Activities on fission yields and beta decay data at NEA

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Outline

- NEA Data Bank
- WPEC: SG25, SG37
- JEFF Project
- JANIS – nuclear data tool
- NEA/CPS
- Summary

OECD Nuclear Energy Agency

The NEA is a specialised semi-autonomous agency of the OECD

Australia	France	Japan	Republic of Korea	Turkey
Austria	Germany	Luxembourg	Russian Federation	United Kingdom
Belgium	Greece	Mexico	Slovak Republic	United States
Canada	Hungary	Netherlands	Slovenia	
Czech Republic	Iceland	Norway	Spain	
Denmark	Ireland	Poland	Sweden	
Finland	Italy	Portugal	Switzerland	

Many areas of work:

- Nuclear safety and regulation
- Nuclear energy development
- Radioactive waste management
- Radiological protection and public health
- Nuclear law
- **Nuclear Science & The Data Bank**

NEA Nuclear Science Committee and the Data Bank

Nuclear Science Committee

- WPNCS – Nuclear Criticality Safety (incl. **ICSBEP and SFCOMPO database**)
- WPRS – Reactor Systems (incl. **IRPhEP and SINBAD databases**)
- WPFC – Fuel Cycle
- WPMM – Multi-scale Modelling of Fuels and Structural Materials
- **WPEC – International Nuclear Data Evaluation Cooperation**

The Data Bank is an international centre of reference with respect to basic nuclear tools, such as computer codes and data, used for the analysis and prediction of phenomena in the nuclear field.

- Computer Program Services (CPS)
- Thermochemical Database (TDB) Project
- **Nuclear Data Services** (e.g. JANIS)
- **Joint Evaluated Fission and Fusion (JEFF) file project**

Main NEA activities related to Nuclear Data

(Differential and integral data)

Collection, compilation, preservation

- Provide up-to-date and reliable data to users (Data Bases, Libraries)
- Update and maintain the **EXFOR database** (NEA DB areas/ NRDC network). Full coverage of experimental results published in open literature

Dissemination

- Provide direct and friendly access to databases (Tools)

Data development, evaluation, validation (WPEC, JEFF)

- Provide a framework for international co-operation
- Provide up-to-date recommended data to users

Workshops, meetings, conferences

- Communicate on activities and services, Promote international co-operation
- Consolidate an expert community (Nuclear Data Weeks)

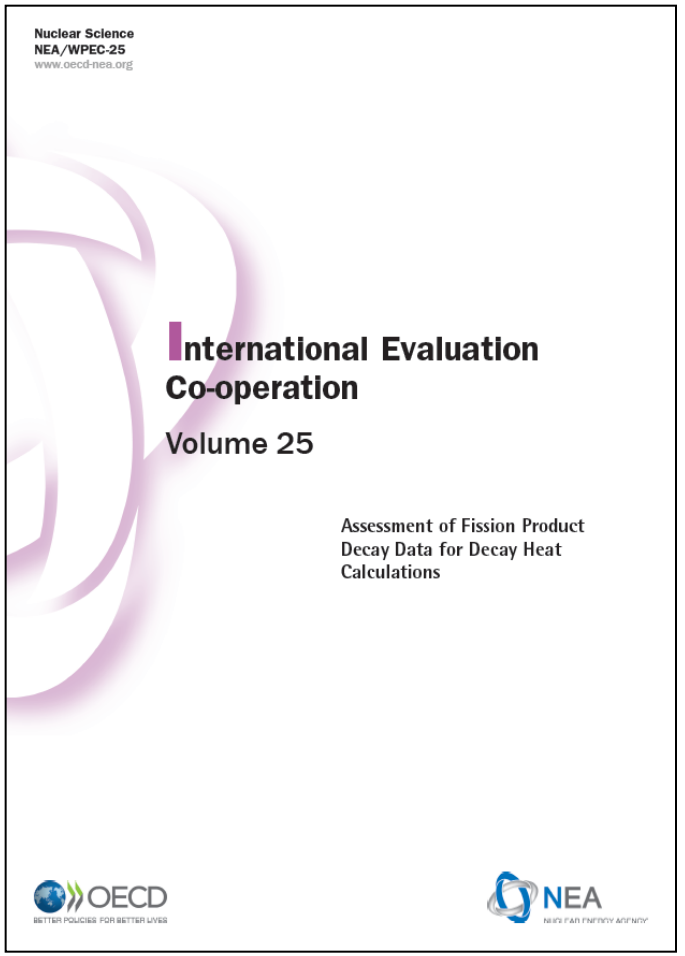
WPEC

- WPEC was established in 1989
- 25 years of co-operation between major evaluation projects: ENDF, JENDL, JEFF (JEF, EFF/EAF), BROND, CENDL, TENDL, FENDL (& other IAEA projects)
- Close collaboration with the IAEA Nuclear Data Section and non-NEA evaluation projects is valuable
- Hundreds of participants from Europe, US, Japan, Korea, Russia, China
- Over 41 short-term Subgroups: SG1, SG2, …, SG40-CIELO, SG41
- 3 longer term Subgroups: A (Nuclear Model Codes), B (Formats & Processing) and **C (HPRL)**
- 31 Subgroup reports on key issues (and more to come…)

WPEC-SG25: Assessment of Fission Product Decay Data for Decay Heat Calculations

- "A **WPEC subgroup (SG)** to address the need for additional fission-product (FP) decay data to be derived experimentally for decay heat calculations.

- "**Recommending a well defined list of FPs for TAGS** – total absorption gamma ray spectroscopy – measurements in order to improve decay heat (DH) calculations without resorting to the introduction of questionable theoretical data."



Nuclear Data Requirements for FPDH

The DH can be derived by summing the products of the nuclear activities in terms of the mean light-particle and electromagnetic energy releases per disintegration of that nuclide:

$$H_{LP}(t) = \sum_{i=1}^{M} \lambda_i^T N_i(t) E_{LP}^i$$

$$H_{EM}(t) = \sum_{i=1}^{M} \lambda_i^T N_i(t) E_{EM}^i$$

The nuclear data requirements for DH calculations:

$Y_{a,k}^i$	independent yields for fission product i;
λ_i	decay constant(s) of fission product i;
E_{HP}^i , E_{LP}^i , E_{EM}^i	mean heavy-particle, light-particle and electromagnetic energy releases per disintegration of nuclide i;

as well as:

k_α, k_{β^-}, k_{β^+}	branching fractions for α, β^- and β^+ decay to (Z,A) nuclide, as used in associated inventory calculations.

Following recent works

- "*Testing JEFF-3.1.1 and ENDF/B-VII.1 Decay and Fission Yield Nuclear Data Libraries with Fission Pulse Neutron Emission and Decay Heat Experiments*"
  Nuclear Data Sheets, Vol. 118, April **2014**, Pages 472-475
  O. Cabellos et al.

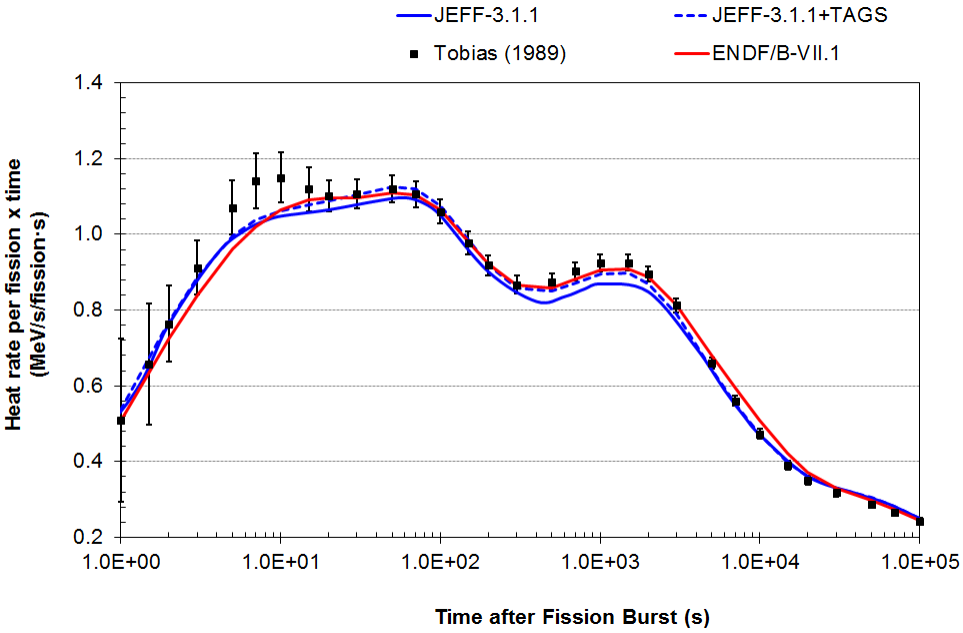


Figure. ^{239}Pu thermal neutron induced fission pulse (β+γ).

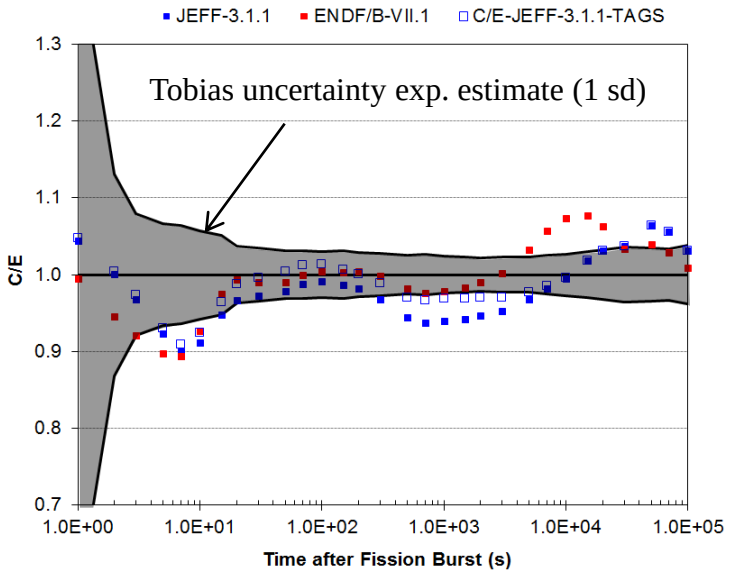


Figure. C/E ^{239}Pu thermal neutron induced fission pulse (β+γ).

Uncertainty Analyses

For unkown $Q_{\beta,\gamma}$ uncert., assumed rel.err. :

alfa (10%), beta (15%) and gamma (15%)

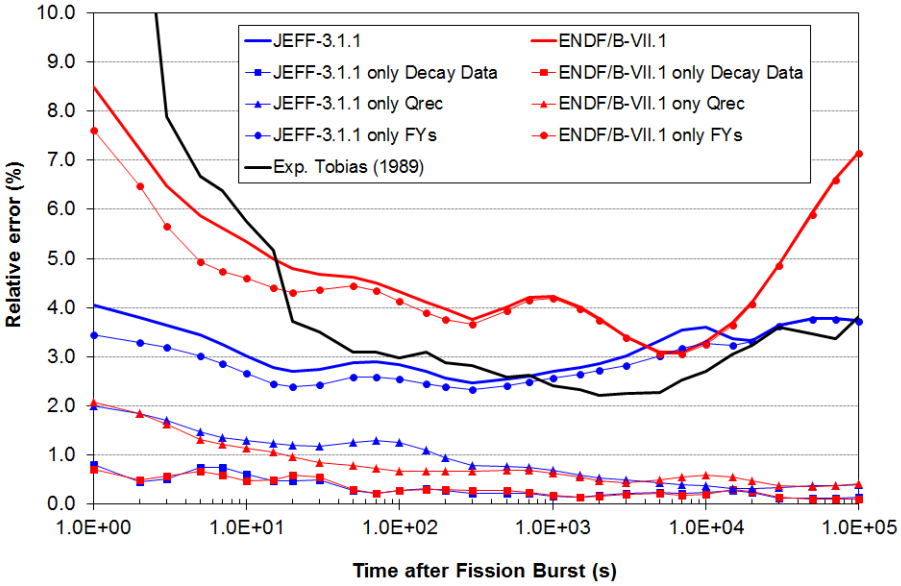


Figure. Relative errors (in %) due to all ND uncertainties propagated together and individually compared to exp. Uncertainty [Tobias, 1989] for Total DH (β+γ) of ^{239}Pu thermal neutron induced fission pulse

Unknown Uncertainties:
Importance at times < 2000 s, about ~ 17% of total DH at 10 s

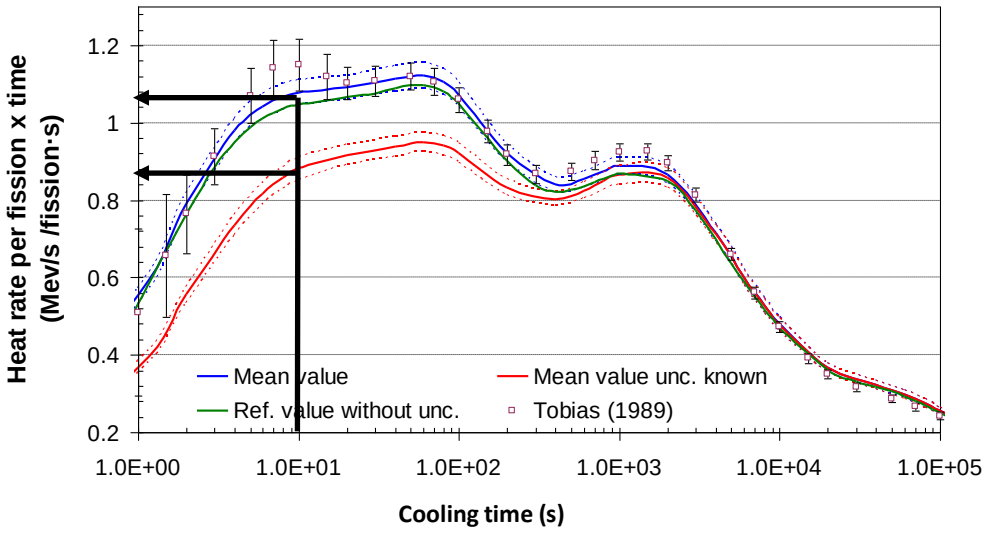


Figure. ^{239}Pu thermal neutron induced fission pulse (β+γ) with JEFF-3.1.1

Uncertainties…

- "*Uncertainty analyses of decay heat summation calculations using JENDL, JEFF, and ENDF files*"
  JNST, Vol.50, No. 8, **2013**, 799-807
  Jun-ichi Katakura

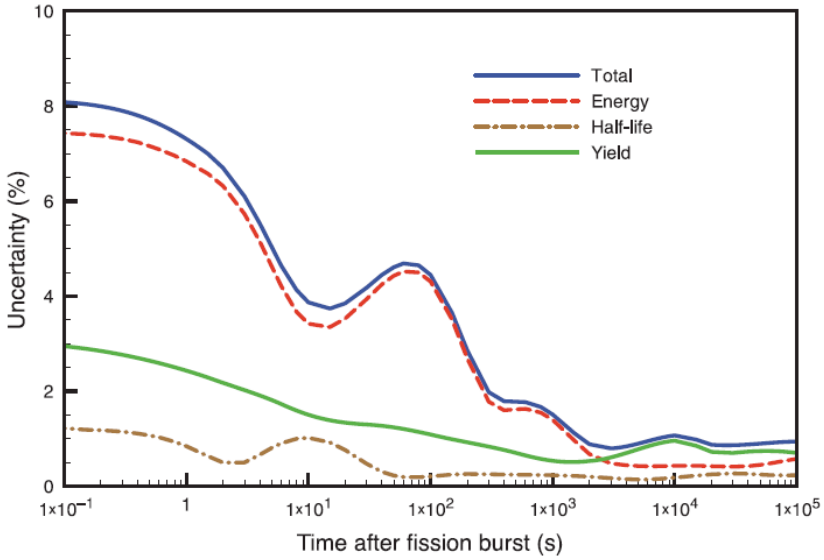


Figure. Uncertainty of decay heat power summation calculation of Pu239 thermal fission with JEFF-3.1.1

- "*Fission yield covariance generation and uncertainty propagation through fission pulse decay heat calculation*"
  ANE, Vol. 69, **2014**, 331-343
  L. Fiorito et al.

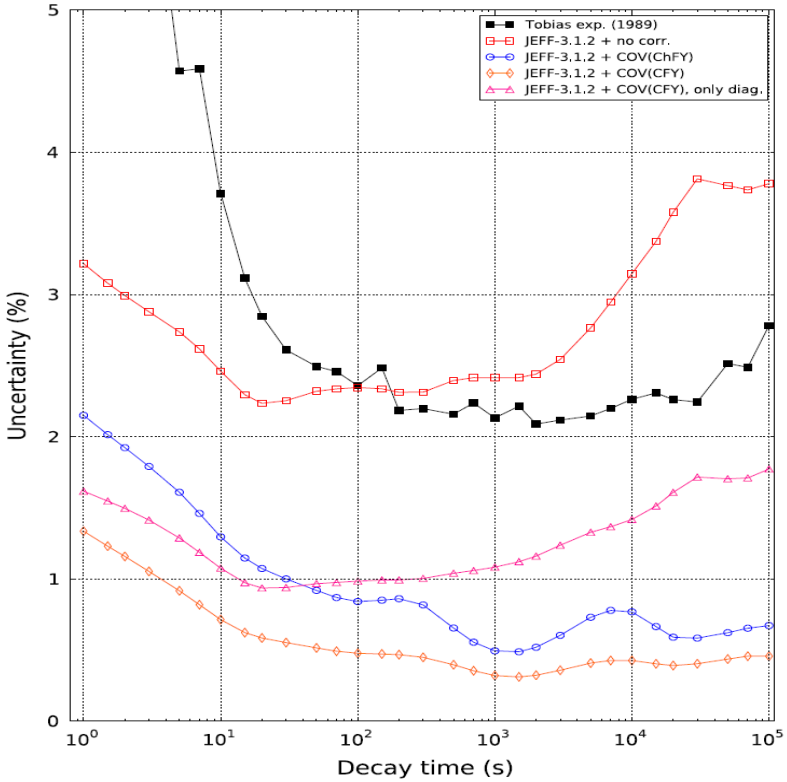


Figure. Uncertainty (%) of decay heat power summation calculation of U235 thermal fission with JEFF-3.1.2

WPEC-SG37: Improved Fission product yield evaluation methodologies

- The subgroup goal is:
  - to develop improved methodologies for future evaluations that are consistent with the new theoretical knowledge and experimental measurements
  - include common covariance methods that will allow calculations with both improved accuracy and the generation of uncertainties on calculated engineering parameters

- Relevance to Evaluated Data Files
  - The results of this work are intended to be a resource advising future evaluators in new fission fragmentation models, evaluation methodologies and the treatment of fission yield covariances

https://www.oecd-nea.org/science/wpec/sg37/

JEFF Project

- The **Joint Evaluated Fission and Fusion File** (JEFF) project is a collaboration between NEA Data Bank member countries.
  - The objective of the JEFF file Project is to develop and promote the use of high quality evaluated nuclear data sets in standard formats for a wide range of scientific and technical applications.
  - The Project members **assess the needs for nuclear data improvements** and address those needs by initiating the necessary measurements and evaluation efforts in their respective institutions or collaborations.

- **Special Purpose files (current data source):**
  - JEFF-3.1.1 Radioactive Decay Data library, for 3852 isotopes *(released in November 2007)*
  - JEFF-3.1.1 Neutron Induced Fission Yields Library *(released in January 2009, minor correction only)*

New JEFF-3.2 Fission Yield Data

- JEFF/DOC-1591, R. Mills
- JEFF-3.2 (now planned for March 2015)
  - Same systems as JEFF-3.1.1
  - Same energies (thermal, fast and 14 MeV)
  - New experimental fission yields
  - Replace empirical models (5 Gaussian, Wahl Zp and Madland/England) with **GEF model** predictions where available (i.e. yields > 10^{-6})
  - Adjust to maintain physical constraints using existing codes
  - Calculate cumulative yields using JEFF-3.2 decay data
  - Generate ENDF format file
  - Test: Decay neutron summation, decay heat pulses, decay heat PWR assemblies, spent fuel assay data.
- JEFF-3.3…

- Q matrix method
  - Given the individual decay branches for all nuclides in the decay paths from one nuclide to a distant daughter it is possible to calculate the fraction of j that decays to I

$$Q_{j,i} = \sum_{allpaths} \left(\prod_{each j \to i} B_{j,j+1} B_{j+1,j+2} \cdots B_{i-1,i} \right)$$

  - The cumulative yield can be predicted as follows:

$$Y_i^c = \sum_j Y_j^i Q_{j,i}$$

Table. List of isotopes with differences larger than 1% between predicted and JEF-3.1.2 CFY values.

Isotope	fycA	diff(%)A	CFY JEFF-3.1.2
10010	1,77E-05	3,55%	1,71E-05
290700	3,61E-09	3,38%	3,49E-09
290701	6,63E-09	8,17%	6,13E-09
380850	1,10E-12	-16,65%	1,32E-12
390971	2,92E-02	3,74%	2,81E-02
400901	6,52E-12	-18,11%	7,96E-12
461111	9,62E-08	-89,12%	8,84E-07
491211	3,45E-05	1,29%	3,41E-05
511290	5,78E-03	13,66%	5,09E-03
511291	1,50E-03	-35,15%	2,32E-03
511300	9,33E-03	-13,73%	1,08E-02
511301	8,05E-03	22,70%	6,56E-03
521290	6,25E-03	3,47%	6,04E-03
521291	2,21E-03	-20,27%	2,77E-03
561320	1,43E-13	********%	4,48E-44
641520	9,05E-13	-22,52%	1,17E-12
651580	9,57E-13	-10,03%	1,06E-12
681700	4,77E-12	-16,12%	5,69E-12

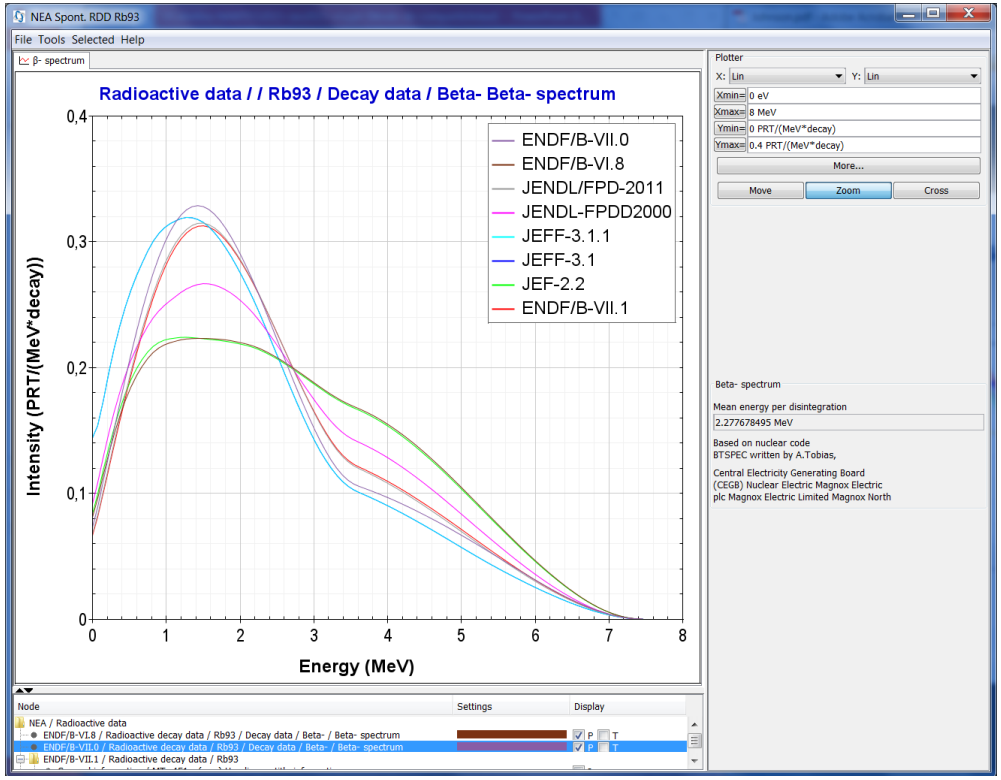
New JEFF-3.2 Radioactive Decay Data

- JEFF/DOC-1598, M.A. Kellet and O.Bersillon
- JEFF-3.2 (planned for December 2014)
  - Complete update to all 900 evaluations coming from ENSDF
    - A decrease in the quality of ~100 ENSDF evaluations
  - Inclusion of IAEA actinide decay data (85 nuclei)
  - Inclusion of IRDFF decay data library (~80 nuclei)
  - Inclusion of updated UKPADD library (~50 nuclei)
  - Inclusion of new DDEP evaluations (~30 nuclei)
  - Inclusion of TAGS results from Tain and Algora et al.
  - Corrections based on feedback to JEFF-3.1.1
  - Test: Decay heat (only test a minor fraction of the library contents)
- JEFF-3.3: ENSDF, NUBASE2012, AME2012,…new evaluations, …

JANIS (Java-based nuclear information software)

- Current version JANIS-4.0
- Beta spectrum using BTSPEC code

  ("The Generation of Beta Spectra from ENDF-6 Evaluations", C.J. Dean, JEF/DOC-949, 2003)



http://www.oecd-nea.org/janis/

NEA Data Bank/ Computer Program Services

- NEA-0866: BTPLOT, **BTSPEC**, EXSPEC, ORDTAB TABLST, Retrieval of ENDF/B Decay Spectra (80's)
  - Implemented in JANIS
- CCC-0657: **BETA-S**, Multi-Group Beta-Ray Spectra (90's)
  - Implemented in SCALE/ORIGENS code
- DLC-0100: **ZZ-ELECSPEC**, "Electron Spectra Data Library from Fission Product Decay"
  - **BETASP**, to compute beta and antineutrino spectra

Other info at NEA Meetings:

- "Evaluation of the shapes of beta spectra ", X. Mougeot et al., JEFF-GEDEPEON Workshop 2011

Summary

- **Prediction of reactor antineutrinos**
  - reactor anomaly: “The Daya Bay data set as a benchmark test”
  - **electron/antineutrino** spectra associated with fission of ^{235,238}U, ^{239,241}Pu
  - **selection of main contributors** (37-Rb-92, 39-Y-96, 55-Cs-142 , …)
- **Calculation of beta/antineutrino spectra:**
  - Approximations: small corrections (δqed ,δWM , δC) as well as the effects of the forbidden decays.
  - Experiments to validate (for high forbidding orders)
  - Activation/burnup codes to compute beta/antineutrino spectra (MURE, SCALE, FISPACT,…)

$$S(E) = \sum \lambda_i N_i S_i(E) / r = \sum CFY_i S_i(E)$$

Used by Vogel et al, 1981, ENDF/B-V

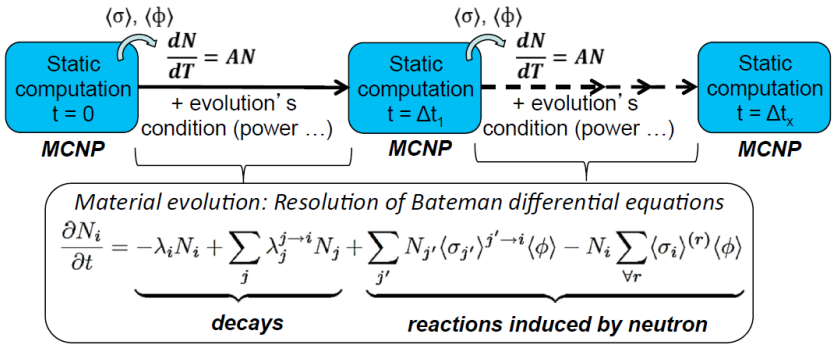


Figure. Typical flowchart for burnup codes

Summary

- **NEA DB Services and Activities:**
  - JEFF: JEFF-3.2 to JEFF-3.3
    - Fission yield (independent and cumulative)
    - Decay data (decay branching ratios, with endpoint E_0 and spins)
    - Checking/Testing libraries: Decay heat, delayed neutrons and **antineutrino emission**
  - WPEC: SG37
  - JANIS: 4.0 to 5.0
  - NEA DB/CPS: BETA-S, BTSPEC,..

References

1. R. Mills. “WPEC subgroup 37 Description”, (2013)
2. “JEFF-3.2 fission yields and future plans”, R. Mills, JEFF/DOC-1591, (2014)
3. “The JEFF-3.2 Radioactive Decay Data Sub-Library”, M.A. Kellet and O.Bersillon, JEFF/DOC-1598 (2014)
4. “The Generation of Beta Spectra from ENDF-6 Evaluations”, C.J. Dean,JEF/DOC-949, (2003)
5. INT Workshop on Nuclear Reactor Neutrinos. Institute for Nuclear Theory, Seattle, November 6-8, 2013
6. NEA Data Bank, http://www.oecd-nea.org/
7. JANIS. http://www.oecd-nea.org/janis/